Description

Method for adjusting a defined oxygen concentration by means of binary lambda regulation in order to diagnose an exhaust gas catalyst

The invention relates to a method for adjusting a defined oxygen concentration by means of binary lambda regulation in order to diagnose an exhaust gas catalyst. The invention also relates to a regulator, which can be used to adjust a defined oxygen concentration.

Exhaust gas catalysts for motor vehicles, hereafter referred to simply as catalysts, are subject to ageing phenomena. Legislation requires catalyst function to be checked in every drive cycle. Reliable catalyst function is determined using the oxygen storage capacity of the catalyst. The catalyst is diagnosed over a plurality of lambda regulation periods, which overlap with catalyst diagnosis periods. To achieve the smallest possible spread in individual diagnosis cycles, a defined oxygen concentration is required in the catalyst that can be repeated in each of the control cycles required for regulation.

In the case of linear lambda regulation this defined oxygen concentration can be achieved with a defined forced activation. Cyclical deviations in respect of the stoichiometric lambda target value are thereby adjusted, whereby half-periods with lean and rich exhaust gas alternate. In the half-period with lean exhaust gas the oxygen storage unit of the catalyst is filled, with excess oxygen being stored, while in the half-period with rich exhaust gas the oxygen storage unit of the catalyst is evacuated, with oxygen being used for the oxidation of exhaust gas components. The instantaneous oxygen input is positive when excess oxygen is stored in the catalyst; it is negative when the

oxygen required in the rich exhaust gas for oxidation reactions
is extracted from the catalyst (if it was stored beforehand).

In the case of binary lambda regulation, regulation is based on
feedback from the lambda probe that the exhaust gases correspond
to a rich or lean mixture. If the lambda probe signal indicates
too rich a fuel mixture, the quantity of fuel is continuously
depleted, whereby the oxygen used for oxidation reactions is
extracted from the catalyst. Depletion takes place until the
lambda probe signal changes and indicates too lean a fuel
mixture, whereby the excess oxygen is stored in the catalyst.
There is then a short dwell time, which can compensate for slight
lambda displacements, i.e. different reaction times on the part
of the lambda probe. A P step (proportional step) of the lambda
control factor then takes place in the enrichment direction and
the fuel mixture is then continuously enriched, until the binary
lambda probe indicates too rich a mixture. This is followed by a
corresponding dwell time and a P step of the lambda control
factor in the depletion direction. This control cycle is
repeated.

The length of the control cycle and the amplitude are essentially
determined by the system transport delay and the reaction time of
the lambda probe. The system transport delay is highly dependent
on the operating point of the engine. This subjects the oxygen
concentration of the catalyst to changes, which make it difficult
to determine the efficiency of the catalyst. Also newer catalysts
have a bigger oxygen storage capacity to comply with future
emission limits (e.g. ULEV, LEV II), so a greater oxygen
concentration is required to diagnose catalyst efficiency than is
automatically adjusted in a control cycle.

To date standard PI lambda regulators were known with extended
dwell times, to achieve greater oxygen concentration. The oxygen
concentration is subject to a high level of spread from control
cycle to control cycle and is a significant function of the
operating point. As a result the individual cycles of the
catalyst efficiency diagnosis are also subject to a high level of
spread, so there is not an adequate distinction between catalysts
of different ages.

The object of the present invention is therefore to provide a
reproducible catalyst efficiency diagnosis that is less
susceptible to malfunction.

This object is achieved by the method according to Claim 1 and
the regulator according to Claim 4.

Further advantageous embodiments of the invention are specified
in the dependent Claims.

According to a first aspect of the present invention a method is
provided for adjusting a defined oxygen concentration to diagnose
a catalyst. Catalyst regulation results in control cycles. The
catalyst is diagnosed at a predetermined oxygen concentration for
each control cycle. A fuel mixture can be adjusted to rich or
lean according to a lambda control factor. Rich or lean exhaust
gas is detected for the fuel mixture, whereby if a lean exhaust
gas is detected for the fuel mixture, the lambda control factor
is increased incrementally and if a rich exhaust gas is detected
for the fuel mixture, the lambda control factor is decreased
incrementally. After a change has been detected from a rich
exhaust gas to a lean exhaust gas or from a lean exhaust gas to a
rich exhaust gas for the fuel mixture, the lambda control factor
is changed by a P step of the lambda control factor.

Also after a change has been detected from a rich exhaust gas to
a lean exhaust gas for the fuel mixture, the lambda control
factor is set to a minimum control factor value during a first
loading period and after a change has been detected from a lean
exhaust gas to a rich exhaust gas for the fuel mixture, the
lambda control factor is set to a maximum control factor value
for a second loading period. The minimum control factor is
determined by a local minimizing of the control factor value of
the current control cycle and the maximum control factor by a
local maximum of the control factor value of the current control
cycle. The first and second loading periods are adjusted so that
the oxygen concentration achieves the defined oxygen
concentration in each control cycle, i.e. the predetermined
oxygen input or oxygen output depending on the half-period of the
control cycle.

The lambda control factor can be used to adjust the mixture to
rich or lean. If a rich exhaust gas is detected with the lambda
probe, the lambda control factor is continuously decreased and
the mixture thereby depleted, until the lambda probe detects a
lean exhaust gas. A dwell time then takes place, during which the
lambda control factor is maintained, to compensate for the
difference in probe switching times or to achieve a slight
mixture displacement, as with a standard lambda regulator. There
is then an additional P step ΔP also in the depletion direction
of the lambda control factor to the minimum control factor value,
which results from the maximum difference in respect of the
lambda control factor mean value, so that the value of the
predetermined oxygen concentration is achieved more quickly. A P
step then takes place to the sum of the incremental decreases and
the additional P step ΔP in the enrichment direction. As a lean
exhaust gas is detected at the lambda probe, the lambda control

factor is now increased continuously and the fuel mixture thereby enriched, until the lambda probe detects a rich exhaust gas. A dwell time then takes place to compensate for the different in probe switching times or to achieve a mixture displacement. An additional P step then takes place in the enrichment direction, which is limited by the maximum difference in respect of the lambda control factor mean value, so that the oxygen output – corresponding to the oxygen input in the lean half-period – is achieved more quickly. For catalyst diagnosis it is important to be able to adjust the amplitude of the lambda fluctuation by means of the additional P step or by limiting the maximum amplitude as a function of the operating point, so that the oxygen storage characteristics in the catalyst can be taken into account during catalyst diagnosis.

The inventive method has the result that in an enrichment half-period – oxygen output from the catalyst – i.e. the mixture is enriched, or a depletion half-period – oxygen input in the catalyst, i.e. the fuel mixture is depleted, after a change has been detected between rich and lean exhaust gas, the fuel mixture is again changed by a ΔP step or set to a maximum difference in respect of the lambda control factor mean value, to achieve the as yet not achieved predefined oxygen concentration as quickly as possible with determined lambda amplitude. Adjustment of the lambda control factor to the maximum control factor value, which is a function of the predetermined oxygen concentration, means that the predetermined defined oxygen concentration is achieved quickly, once a change has been detected between rich and lean exhaust gas.

After the predetermined oxygen concentration has been achieved, the lambda control factor is reset quickly by the sum of the P steps (standard P step + ΔP step) implemented during the course

of the respective half-period. As before the lambda control
factor is now increased or decreased step by step and the fuel
mixture thereby depleted or enriched.

The predetermined defined oxygen concentration is preferably
determined by the maximum oxygen storage capacity of an ageing
catalyst. In this way the catalyst efficiency diagnosis can also
be carried out even with an ageing catalyst at a catalyst oxygen
concentration that can be repeated in every control cycle and is
a function of the operating point.

The minimum or maximum control factor value is preferably
determined by the difference between the lambda control factor
the lambda control factor mean value and is predetermined by the
oxygen storage speed of the catalyst. The oxygen storage speed of
the catalyst is a function of the throughflow of the exhaust
gases through the catalyst and the catalyst temperature and
essentially describes the maximum quantity of oxygen that can
diffuse into the catalyst and be bound per unit of time. The
control factor value is thus adjusted to a minimum or maximum
value, at which the oxygen diffusion speed is not yet exceeded
and which results in measurable oxygen behind the catalyst, even
though the storage capacity has not yet been exceeded.

According to a further aspect of the present invention a
regulator is provided for diagnosing a regulated catalyst. The
regulator adjusts a defined maximum oxygen concentration for each
control cycle to carry out a catalyst diagnosis. The regulator
controls the composition of a fuel mixture, whereby regulation
results in control cycles. The regulator can be connected for
this purpose to an injection system, to adjust the fuel mixture
to rich or lean according to a lambda control factor. A sensor is
used to detect lean or rich exhaust gas. The regulator increases

the lambda control factor incrementally in the event of lean
exhaust gas and

decreases the lambda control factor incrementally in the event of
rich exhaust gas. The regulator sets the lambda control factor to
a minimum control factor after a change has been detected from a
rich exhaust gas to a lean exhaust gas for the fuel mixture
during a first loading period, whereby after the end of the first
loading period the control factor value is set to a mean value of
the lambda control factor. The regulator also sets the lambda
control factor to a maximum control factor value during a second
loading period, after a change has been detected from a lean
exhaust gas to a rich exhaust gas for the fuel mixture. After the
end of the second loading period the lambda control factor is
changed to a mean value of the lambda control factor by the
regulator. The first and second loading times are determined such
that the oxygen concentration, i.e. the oxygen input or output,
achieves the predetermined maximum positive or negative oxygen
concentration in each control cycle.

The inventive regulator has the advantage that it regulates the
fuel mixture such that the oxygen concentration is the same in
every control cycle, so that a reproducible oxygen concentration
over a plurality of control cycles allows reproducible catalyst
diagnosis with less susceptibility to malfunction.

The regulator can preferably be operated in a diagnosis mode to
diagnose a catalyst and can be operated in a second mode, in
which the regulator regulates in the same way as a hitherto known
standard PI lambda regulator. In this way catalyst diagnosis only
represents an operating mode of an already provided regulator so
that the structure of the overall system comprising a regulator,
injection system, engine and catalyst does not essentially have
to be changed.

A preferred embodiment of the invention is described in more
detail below with reference to the accompanying drawings, in
which:

Figure 1   shows an engine system with a regulator according to a
preferred embodiment of the invention; and

Figure 2   shows the characteristics of the lambda control factor
over a plurality of control cycles.

Figure 1 shows a functional diagram of an engine system. The
engine system has a mixer 1, which supplies a fuel mixture
comprising air and engine fuel to an internal combustion engine
2. The internal combustion engine 2 combusts the fuel mixture and
emits exhaust gases, which are fed to a three-way catalyst 5. The
exhaust gas emitted by the internal combustion engine 2 is
directed via a lambda probe 4, which determines from the
composition of the exhaust gas whether the mixture is richer or
leaner than the stoichiometric fuel mixture.

The lambda probe 4 is connected to a regulator 3, so that a
measurement value measured by the lambda probe 4 is available as
an input value for the regulator. The regulator 3 is a binary
regulator, which obtains as an input variable from the lambda
probe just the information whether the exhaust gas corresponds to
a too rich or too lean fuel mixture. The regulator 3 uses this to
generate a correcting variable, which is transmitted to the mixer
1. The correcting variable is the lambda control factor, which
indicates the factor by which the basic fuel mixture ratio
predetermined by an injection system (not shown) should be
changed.

A catalyst efficiency diagnosis can be carried out by checking
the performance of the catalyst 5. For such an efficiency
diagnosis it is important for there to be as little spread as
possible between individual diagnosis cycles. This can be
achieved by loading the catalyst with the same quantity of oxygen
in each control cycle. While it is possible to achieve the same
oxygen concentration in the control cycles with a defined forced
activation in the case of linear lambda regulation, this is not
possible in the case of binary lambda regulation. Binary lambda
regulation uses the lambda control factor to regulate the mixture
composition with reference to a binary signal that is a function
of the lambda probe or the probe voltage U_λ, which indicates
whether the fuel mixture is too rich or too lean, whereby the
control deviation is not known.

As the length of the control cycles is a function of the
operating point, there is not a constant oxygen concentration
over the control cycles during normal operation. After activation
of the catalyst efficiency diagnosis however, the device switches
to lambda regulation based on oxygen concentration. Figure 2
shows the characteristics over time of the lambda control factor.

In a first time segment T1 the regulator 3 is in normal
operation, i.e. lambda control is [lacuna] by cyclical
fluctuation of the lambda control factor about a mean value
corresponding to a lambda value of around 1, i.e. a
stoichiometric mean value. The control cycles are referred to as
lean half-periods when the lambda control factor is smaller than
its mean value and as rich half-periods when the lambda control
factor is greater than its mean value.

During the lean half-period there is more oxygen in the fuel
mixture than is predetermined by the stoichiometric mean, i.e.

than is required for optimum operation of the catalyst. This
results in a positive oxygen concentration during the lean half-
period. During the rich half-period there is less oxygen in the
fuel mixture than is predetermined by the stoichiometric mean,
i.e. less than is required for optimum operation, so oxygen is
emitted from the catalyst to the exhaust gas for oxidation
reactions. This is referred to as a negative oxygen concentration
(oxygen output).

Lambda regulation is achieved by a gradual increase in the lambda
control factor in the phase, in which the lambda probe reports
lean exhaust gas, as a result of which the fuel mixture is
increasingly enriched. This is represented by the step by step
increase in the lambda control factor over time in the first time
segment T1. As soon as the lambda probe 4 detects that the fuel
mixture is too rich, the step by step increase in the lambda
control factor is halted.

As the lambda probe 4 frequently has an asymmetrical reaction
time, i.e. detects a change from a lean to a rich mixture or from
a rich to a lean mixture with different reaction times, a first
dwell time TDLY1 can be provided, during which after
identification of a change from a lean to a rich mixture and
vice-versa the lambda factor is maintained, before it is quickly
reset by a P step. For the following lean half-period, i.e. after
the P step of the lambda control factor, the lambda control
factor is decreased continuously, i.e. step by step, so the fuel
mixture is depleted. If the lambda probe now indicates that the
fuel mixture is too lean, the step by step decrease in the lambda
control factor is halted and after a second dwell time TDLY2 a P
step is effected in the lambda control factor. The second dwell
time TDLY2 can be different from the first dwell time TDLY1.

A second time segment T2 now shows the characteristics of the
lambda control factor in a diagnosis operating mode, in which the
performance of the catalyst is to be checked. In order to be able
to carry out the diagnosis of catalyst performance with as little
spread as possible between the diagnosis cycles, a constant
oxygen concentration is required for all control cycles. In other
words the change in oxygen concentration should be essentially
the same in both the lean half-periods and the rich half-periods.
It is irrelevant here whether it is a positive or a negative
change in oxygen concentration.

In diagnosis operating mode regulation takes place in essentially
the same way as in normal operating mode, as described above. As
soon as a change has been detected from a too rich to a too lean
fuel mixture during a lean half-period, the lambda control factor
is first maintained as constant after a dwell time TDLY and then
after the dwell time it is further depleted by a ΔP step. The
period for which the maximum value should be maintained for the
lambda control factor is based on the oxygen concentration
achieved in the relevant half-period. In other words the maximum
value of the lambda control factor is maintained until a defined
oxygen concentration has been achieved in said control cycle.

To determine the oxygen concentration of the control cycle the
characteristics over time of the oxygen input have to be
determined for each half-period. The following applies:

$$m_{O_2} = 23\% \bullet \int_0^{t_M} \left(1 - \frac{1}{\lambda}\right) \bullet \dot{m_L} \, dt$$

whereby m_{O_2} represents the oxygen concentration, t_M the time of
the half-period, λ the lambda value of the fuel mixture, (λ = 1

for the stoichiometric mean) and $\dot{m}_L$ the mass air flow. As the λ
is a function of the lambda control factor, the following
results:

$$m_{O_2} = 23\% \bullet \int_0^{t_M} \left(1 - \frac{1}{\lambda_{t\,arg} + \Delta\lambda_{t\,arg}} \right) \bullet \dot{m}_L dt$$

whereby $\lambda_{t\,arg}$ represents the mean value of the λ regulator over a

period of λ control fluctuation and $\Delta\lambda_{t\,arg}$ the characteristics of

depletion. The factor 23% results from the proportion of oxygen
in the air.

$\Delta\lambda_{t\,arg}$ is positive during the lean half-period and negative

during the rich half-period. The formulae can be used in the same
way for the oxygen evacuation process during the rich half-
period.

In the case of binary lambda control the value λ is not known
directly. λ can be calculated from the lambda control factor,
which represents a multiplying factor of the basic injection
quantity. The lambda control factor corresponds in converse
proportion to the λ displacement. The respective mean value is a
mean control intervention over a control cycle and corresponds to
$\lambda_{t\,arg}$ and $\Delta\lambda_{t\,arg}$ is the difference between current value and mean

value of the lambda control factor. The following results:

$$m_{O_2} = 23\% \bullet \int_0^{t_M} \left(1 - \frac{FAC\_LAM - FAC\_LAM\_MW}{FAC\_LAM\_MV} \right) \bullet \dot{m}_L dt$$

where FAC_LAM is the instantaneous multiplying lambda control
factor and FAC_LAM_MV its mean value over the entire lambda
control period. This integration allows the oxygen concentration
to be determined for every lean and rich half-period of lambda

regulation. As the current mass air flow $\dot{m}_L$ is taken into
account, the change in the operating point of the engine is also
taken into account.

To avoid displacement of the lambda value, in diagnosis operating
mode the dwell time and range of the step by step change in the
lambda control factor are kept the same. To achieve the required
predetermined oxygen concentration as quickly as possible however
after the dwell time the lambda control factor can be increased
in the lean half-period by a P step ΔP and decreased during the
rich half-period by a P step ΔP, in order to achieve the
increased oxygen concentration – positively or negatively – for
the catalyst efficiency diagnosis more quickly.

The period during which the maximum or minimum value of the
lambda control factor is output by the regulator 3 is a function
of the required oxygen concentration, i.e. the lambda control
factor is maintained until the required oxygen concentration
according to the above formula is achieved.

When the required oxygen concentration is achieved the lambda
control factor is reset by the sum of the lambda control factor
changes effected during the step by step increases or decreases
in the respective half-period and the additional P step ΔP. The
sum results from the sum of all step by step increases or
decreases of the lambda control factor and the additional
increase or decrease to the maximum difference or minimum value

of the lambda control factor over the entire lambda control
cycle.

The maximum or minimum value of the lambda control factor results
from the maximum diffusion speed of the oxygen into the active
layer or washcoat of the catalyst or out. The maximum or minimum
value of the lambda control factor is therefore determined by how
quickly oxygen can be absorbed from the exhaust gas stream, which
is guided through the catalyst, and emitted into the active layer
or washcoat. The maximum or minimum control factor therefore
results from a predetermined oxygen concentration value. If the
lambda control factor is set as greater than the maximum value or
smaller than the minimum value, this does not mean that more
oxygen is absorbed or emitted. As a result the catalyst is no
longer able to buffer the λ

fluctuations produced by the control cycles in respect of the
output of the catalyst, so that no fluctuations can be detected
there, even though the oxygen storage capacity of the catalyst
has not yet been exhausted.

The defined oxygen concentration, which is set to diagnose
catalyst efficiency, corresponds to the oxygen storage capacity
of an ageing catalyst, which still complies with the requirements
relating to efficiency.

The efficiency diagnosis takes place using a λ monitor probe (not
shown), which is also a lambda probe, whereby the monitor probe
is placed in the exhaust gas stream behind the catalyst 5. The
monitor probe then detects whether a constant lambda value has
been achieved or whether the lambda value fluctuates according to
the control cycle. If the lambda value measured by the monitor
probe fluctuates, the catalyst being checked does not have

adequate oxygen storage capacity and a defective or ageing
catalyst is detected.

The degree of ageing of the lambda control probe and the
resulting delay in detecting the exhaust gas change rich <-> lean
are also taken into account in the oxygen concentration
calculation and target value adjustment. If the reaction time of
the lambda probe is extended due to ageing phenomena, the step by
step increase or decrease in the lambda control factor is carried
out for longer so that a higher oxygen concentration is achieved
in the catalyst as well as a higher amplitude in the λ control
factor and λ fluctuation before a change is detected between a
too rich and a too lean fuel mixture. The amplitude of the lambda
control factor is therefore limited to the maximum difference in
respect of the lambda control factor mean value, which means that
the additional step ΔP is not completed.

The idea behind the invention is to supply a method for binary
lambda regulation based on oxygen concentration, whereby after
the dwell time a further step of the lambda control factor in the
original direction is provided, to achieve the increased oxygen
concentration more quickly. However in order to prevent an
excessive increase in the amplitude of the lambda control factor
and lambda fluctuation due to ageing of the lambda control probe
and its associated extension of probe reaction time, the
additional P step is limited so when added to the I part
integrated over a half-period it cannot exceed the maximum
difference in respect of the mean value of the lambda control
factor. Thus even with an ageing binary lambda control probe with
a slower dynamic it is possible to prevent an increase occurring
in the lambda amplitude.

The catalyst oxygen balance is achieved solely via the oxygen
concentration integrals, which have to balance each other out in
the rich and lean periods. This results in an increase in the
accuracy of oxygen concentration adjustment, primarily in non-
stationary processes or minor malfunctions. Lambda control based
on oxygen concentration allows the times, during which the
maximum or minimum lambda control factor is maintained or the
amplitude increases to be adjusted adaptively based on the
maximum or minimum lambda control factor.

Alternatively after detection of a change between a lean and rich
fuel mixture, the lambda control factor is not adjusted to a
maximum or minimum value but the lambda control factor is
maintained until the predetermined oxygen concentration is
achieved.